Lecture 27. Radiative forcing: gases, aerosols, clouds.

Objectives:

1. Radiative forcing of aerosol and clouds.

2. Radiative forcing of aerosols and clouds vs. greenhouse gases.

Recommended reading:

L02: 8.4, 8.6

Additional reading:

IPCC (2001). Intergovernmental Panel on Climate Change: Report on Climate Change 2001

Haywood J. and O. Boucher, Estimates of the direct and indirect radiative forcing due to tropospheric aerosols: A review. Review of Geophysics 38, 513-543, 2000.

1. Radiative forcing of aerosols and clouds.

Climate forcing is a change imposed on the climate system that has the potential to alter global temperature.

Stand-alone radiative transfer codes:

Radiative forcing, ΔF (W m^{-2}), is a change of net radiative flux (longwave and shortwave) **at the top of the atmosphere** due to an external perturbation.

GCM models (official IPCC definition):

Radiative forcing is a change in net radiative flux at the tropopause after stratosphere comes back into equilibrium.

Direct and indirect radiative forcings of aerosols:

Direct forcing is due to direct interaction of aerosols with radiation field

Indirect forcing: aerosols affect clouds (or other radiatively active species) => altered clouds change the net flux

Indirect aerosol radiative forcing of climate:

1) altering clouds:

aerosols serve as the cloud nuclei => modify the amount and properties of clouds => perturbed clouds affect the Earth's radiation balance;

2) changing atmospheric chemical composition:

aerosols affect the distribution and amount of radiatively active atmospheric gases=> affects the Earth's radiation balance

Direct radiative forcing of aerosols (or clouds) is defined as a difference between the net fluxes in 'clean' and perturbed atmospheric conditions.

$$\Delta F = F_{aer}(TOA) - F_{clean}(TOA) \qquad [27.1]$$

where

$F_{aer}(TOA)$ is the net total flux at the top of the atmosphere in the presence of aerosols (or clouds);

$F_{clean}(TOA)$ is the net total flux at the top of the 'clean' atmosphere.

Direct radiative forcing of aerosols (or clouds) can be expressed as

$$\Delta F = SWF + LWF \qquad [27.2]$$

where

SWF is the shortwave (solar) component of radiative forcing;

LWF is the longwave (thermal IR) component of radiative forcing;

$$SWF = F^{\uparrow}_{SW,clean}(TOA) - F^{\uparrow}_{SW,aer}(TOA) \qquad [27.3]$$

$$LWF = F^{\uparrow}_{LW,clean}(TOA) - F^{\uparrow}_{LW,aer}(TOA) \qquad [27.4]$$

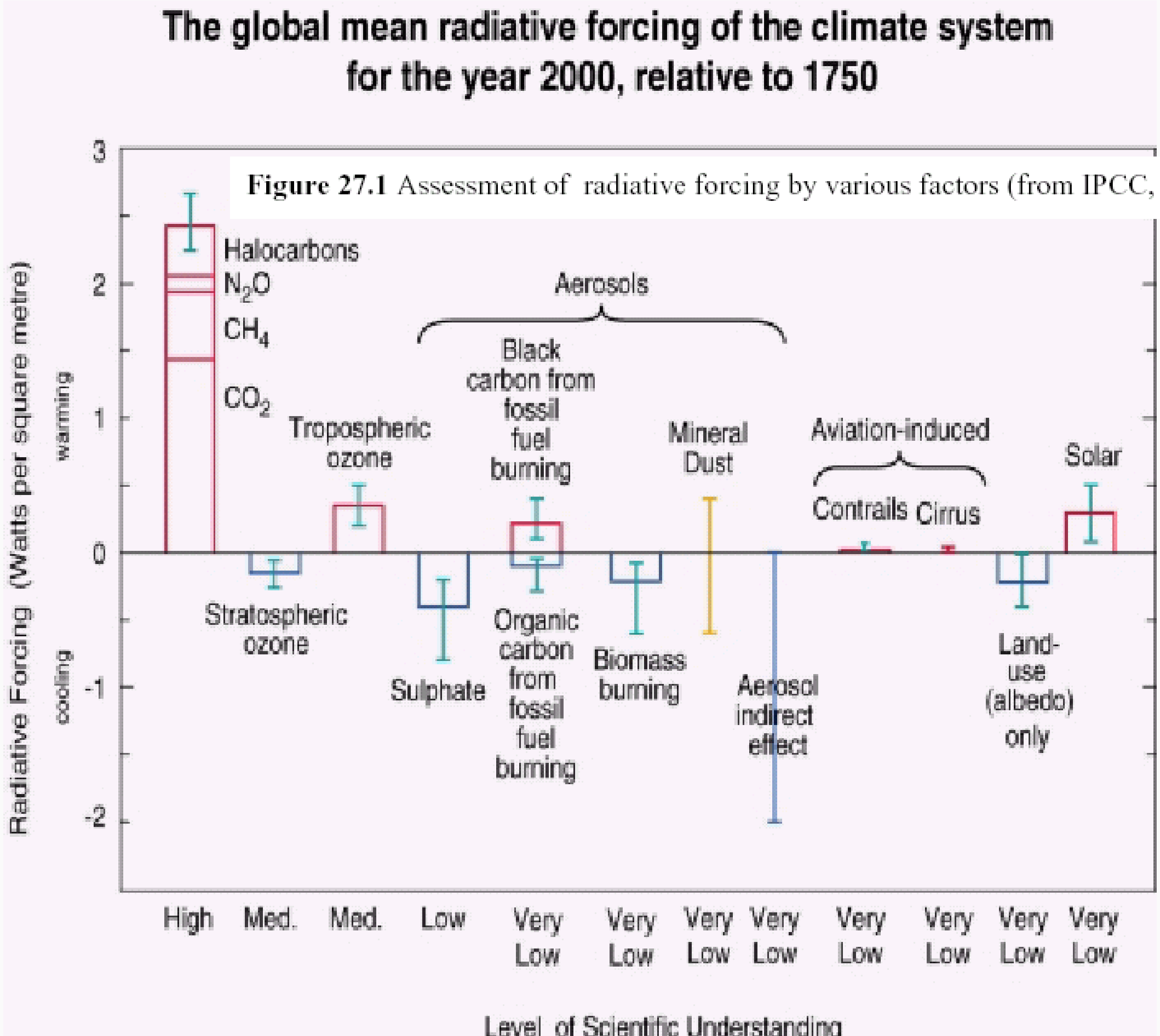

Figure 27.1 Assessment of radiative forcing by various factors (from IPCC, 2001)

✓ ***Radiative forcing of aerosols has the complex spatial distribution:***

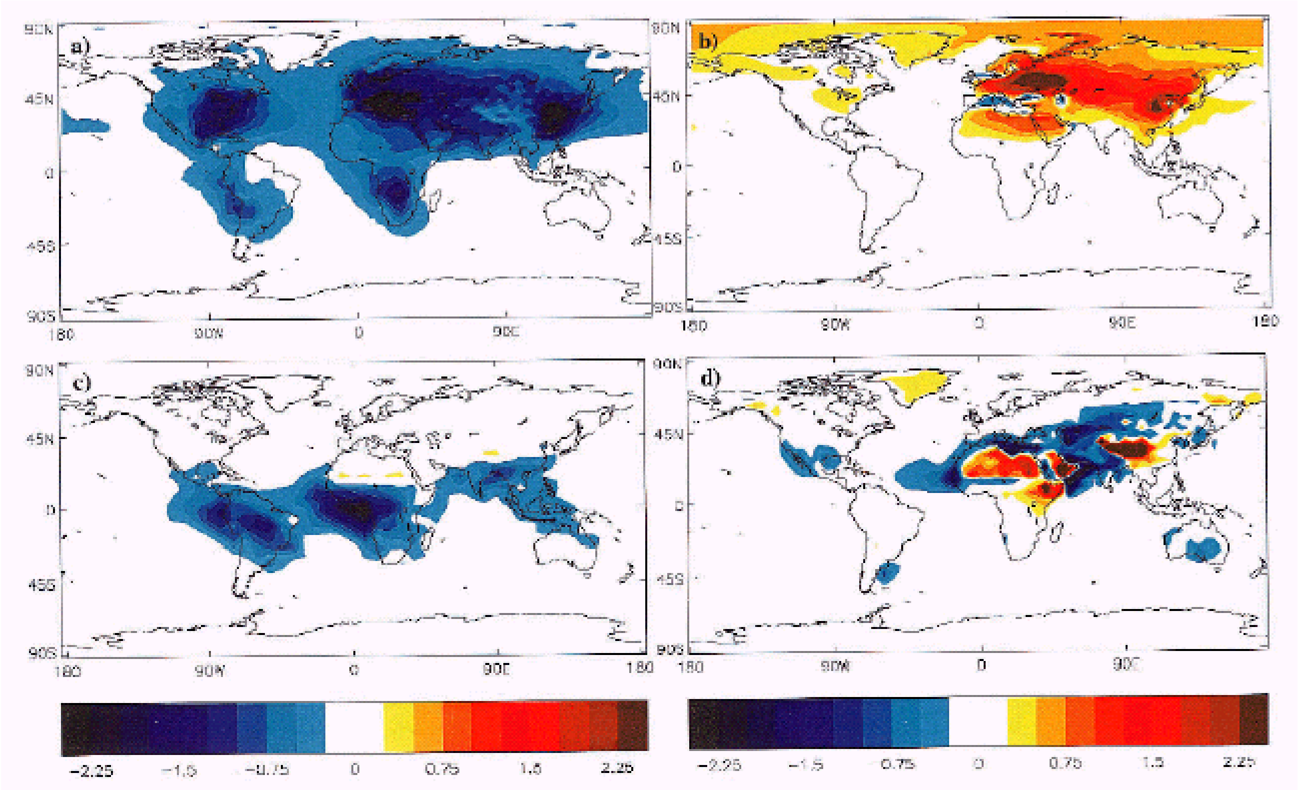

Figure 27.2 Model predictions of the radiative forcing (W/m2) :

(a) the direct radiative forcing of sulfate aerosols (Haywood et al., 1997);

(b) the direct radiative forcing of organic carbon and black carbon from fossil fuel burning (Penner et al., 1998);

(c) the direct radiative forcing of organic carbon and black carbon from biomass burning (Grant et al., 1999)

(d) the direct radiative forcing of mineral dust (Tegen et al., 1996)

➢ ***Diurnal cycle of radiative forcing***

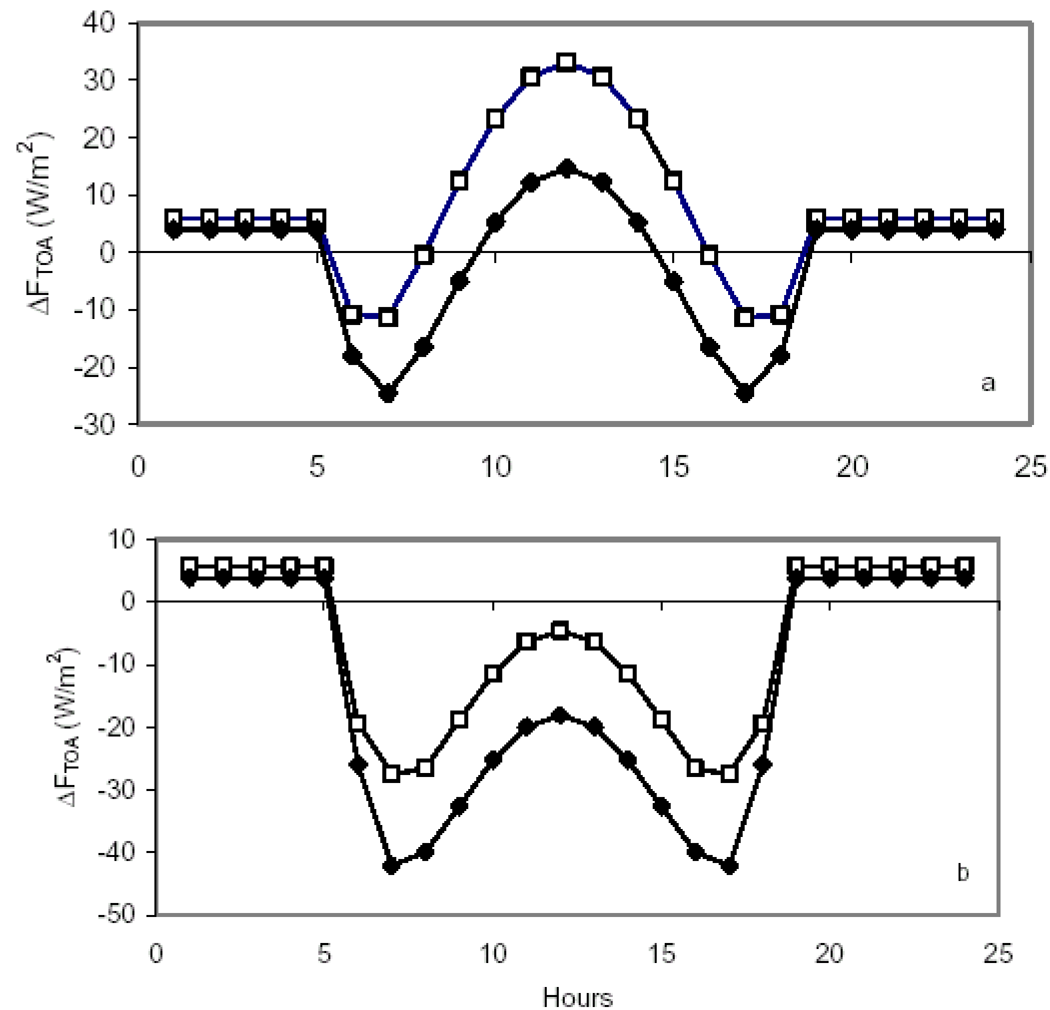

Figure 27.2 Diurnal cycle of net radiative forcing (30^{o}N, summer) for Saharan (squares) and Afghan dust (diamonds) (a) over the land, and (b) over the ocean, τ_{dust} (0.5 μm) = 0.5.

2. Radiative forcing of aerosols and clouds vs. greenhouse gases.

Key differences between aerosol forcing and GHG forcing:

- The two forcings (GHG and aerosol) have very different spatial and temporal distributions: GHG operates day and night, whether clear or cloudy, and is at a maximum in the hottest, driest places on Earth. In contrast, forcing by anthropogenic aerosols occurs mainly by day, and because of the relatively short residence time of aerosols, is concentrated near aerosol sources and downwind from the sources.

- Determination of GHG forcing is well-posed problem in radiative transfer (because IR absorption is well quantified for all GHG gases). Determination of direct and indirect aerosol forcings remains an unresolved problem (because of complex spatial and temporal distribution of aerosol, complex chemical composition, complex evolution processes).